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FUNDING SITE CLEANUP AT CLOSING ARMY INSTALLATIONS: A STOCHASTIC OPTIMIZATION APPROACH

by

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December 2001

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To reduce domestic military infrastructure, the United States enacted two laws that instituted rounds of base realignment and closure (BRAC) in 1988, 1991, 1993, and 1995. As a result of these BRAC rounds, the United States Army has closed or realigned 139 installations. Environmental cleanup is almost $2.3 billion (43%) of the entire cost associated with the closure and realignment of these 139 Army installations. The United States Army Base Realignment and Closure Office (BRACO) uses an integer linear program called BAEC (Budget Allocation for Environmental Cleanup) to help determine how to allocate limited yearly funding to installations for environmental cleanup. Considering environmental policies and yearly installation funding requests from 2002 to 2015, this thesis modifies BAEC to better account for uncertainty in future environmental cleanup cost estimates. Based on historic data that show most environmental cleanup cost estimates increase over time, the stochastic BAEC model recommends funding fewer sites than the deterministic BAEC model recommends. The stochastic BAEC model thereby provides funding recommendations with a better chance of staying within limited available yearly funding.

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FUNDING SITE CLEANUP AT CLOSING ARMY INSTALLATIONS: A STOCHASTIC OPTIMIZATION APPROACH

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ABSTRACT

To reduce domestic military infrastructure, the United States enacted two laws that instituted rounds of base realignment and closure (BRAC) in 1988, 1991, 1993, and 1995. As a result of these BRAC rounds, the United States Army has closed or realigned 139 installations. Environmental cleanup is almost $2.3 billion (43%) of the entire cost through 2001 associated with the closure and realignment of these 139 Army installations. The United States Army Base Realignment and Closure Office (BRACO) uses an integer linear program called BAEC (Budget Allocation for Environmental Cleanup) to help determine how to allocate limited yearly funding to installations for environmental cleanup. Considering environmental policies and yearly installation funding requests from 2002 to 2015, this thesis modifies BAEC to better account for uncertainty in future environmental cleanup cost. Based on historic data that show most environmental cleanup cost estimates increase over time, the stochastic BAEC model recommends funding fewer sites than the deterministic BAEC model recommends. The stochastic BAEC model thereby provides funding recommendations with a better chance of staying within limited available yearly funding.

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LIST OF ACRONYMS AND ABBREVIATIONS

AMC	Army Materiel Command
BAEC	Budget Allocation for Environmental Cleanup (Deterministic Model)
BAECS	Budget Allocation for Environmental Cleanup (Stochastic Model)
BRAC	Base Realignment and Closure
BRACO	United States Army Base Realignment and Closure Office
DoD	United States Department of Defense
FORSCOM	Forces Command
GAMS	General Algebraic Modeling System
IRA	Interim Remedial Action
LTM	Long Term Monitoring
MACOM	Major Army Command
MDW	Military District of Washington
MEDCOM	Medical Command
MTMC	Military Traffic Management Command
RA-C	Remedial Action Construction
RA-O	Remedial Action Operation
RD	Remedy Decision
RI	Remedial Investigation
SI	Site Investigation
TRADOC	Training and Doctrine Command
US	United States
USARPAC	United States Army Pacific Command

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EXECUTIVE SUMMARY

To reduce domestic military infrastructure, the United States (US) enacted two laws that instituted rounds of base realignment and closure (BRAC) in 1988, 1991, 1993, and 1995. As a result of these BRAC rounds, the US Army has closed or realigned 139 installations. Environmental cleanup is almost \$2.3 billion (43%) of the entire cost associated with the closure and realignment of these 139 Army installations. The US Army Base Realignment and Closure Office (BRACO) uses an integer-linear program called BAEC (Budget Allocation for Environmental Cleanup) to help determine how to allocate limited yearly funding to installations for environmental cleanup. Considering environmental policies and yearly funding requests from 2002 to 2015, this thesis modifies BAEC and extends it to account for uncertainty in future environmental cleanup costs.

BRACO funds environmental cleanup of sites on installations that are closing or being realigned. It is currently funding environmental cleanup at 334 sites (a site is a sub-element of an installation, such as a training area, housing area or military building) on 54 installations. BRACO's yearly budget from 2002 to 2007 for environmental cleanup at these installations, totaling over \$414 million, is not enough to support every installation's complete funding request.

The current BAEC model helps BRACO decide how to allocate funds to installations for environmental cleanup. However, BAEC, a deterministic model, does not directly consider how actual costs for environmental cleanup as well as the estimates can change over time. This thesis modifies BAEC and presents a new stochastic model, BAECS, to help account for uncertainty in future costs.

In order to better estimate future costs, we first compare some past environmental cleanup cost estimate data with more recent data. We find the average percent change in yearly cost estimates across all sites at each installation generally have an increasing trend over time. Using these installation estimates, we generate future cost estimates for BAECS assuming: 1) cost estimates have a normal distribution; 2) if the old estimate is zero dollars, the new one is also zero dollars; and 3) all sites at the same installation

experience the same relative change in a given year but estimates change from year to year.

We solve BAECS with 50 scenarios, where a single scenario is one generated estimate of the future cost to cleanup each site each year. The primary difference between the solutions provided by BAEC and BAECS is the number of sites funded without delay. We have a total of 334 sites to fund. 192 of these sites are subject to a mandatory no-delay policy (must-fund sites). For the remaining 142 sites, BAEC funds 87 sites without delay, whereas BAECS funds only three sites without delay. Unlike BAEC, BAECS anticipates an overall increase in installations' future costs and therefore does not suggest spending all the budget in the earlier years (2002 through 2005). It recommends reserving some of its budget as insurance for uncertainty in future costs.

There are tradeoffs in choosing the funding option selections suggested by either BAEC or BAECS. With the BAEC solution, we base funding recommendations on current site environmental cleanup estimates and use all of the budget available to plan the closeout of more sites between 2002 and 2007. The risk with the BAEC solution is not having sufficient funds available if the actual cleanup cost increases. With the BAECS solution, we close less sites but have a better chance of staying within budget (according to our assumptions about how cost estimates change). The risk with the BAECS solution is not fully executing funds available and thereby unnecessarily delaying cleanup.

I. INTRODUCTION

To reduce domestic military infrastructure, the United States (US) enacted two laws that instituted rounds of base realignment and closure (BRAC) in 1988, 1991, 1993, and 1995 [US General Accounting Office 1996]. As a result of these BRAC rounds, the US Army has closed or realigned 139 installations. Environmental cleanup is almost $2.3 billion (43%) of the entire cost associated with the closure and realignment of these 139 Army installations [Oremis 2000]. The US Army Base Realignment and Closure Office (BRACO) uses an integer-linear program called BAEC (Budget Allocation for Environmental Cleanup) [Oremis 2000] to help determine how to allocate limited yearly funding to installations for environmental cleanup. This thesis modifies BAEC and extends it to account for uncertainty in future environmental cleanup cost estimates.

A. ENVIRONMENTAL CLEANUP

While reducing its infrastructure, the US Department of Defense (DoD) has had to speed up the sale or transfer of unneeded property. In most cases, base cleanup is a prerequisite for the title transfer of BRAC property to nonfederal parties or authorities. While accomplishing cleanup, DoD must comply with both state and federal laws and regulations [US General Accounting Office 1996].

BRACO is currently funding environmental cleanup at 334 sites (a site is a sub-element of an installation, such as a training area, housing area or military building) on 54 installations [Martin 2001]. (See the Appendix for a complete list of these installations.) There are seven formal phases associated with environmental cleanup at these BRAC installations (Figure 1): *Site Investigation* (SI), *Remedial Investigation* (RI), *Remedy Decision* (RD), *Remedial Action Construction* (RA-C), *Remedial Action Operation* (RA-O), *Long Term Monitoring* (LTM) and *Interim Remedial Actions* (IRA). Each site starts the cleanup process with the site identification and SI phase. A site does not have to go through all the phases while other sites may need indefinite LTM. Site *closeout* occurs when a site completes all the necessary phases.

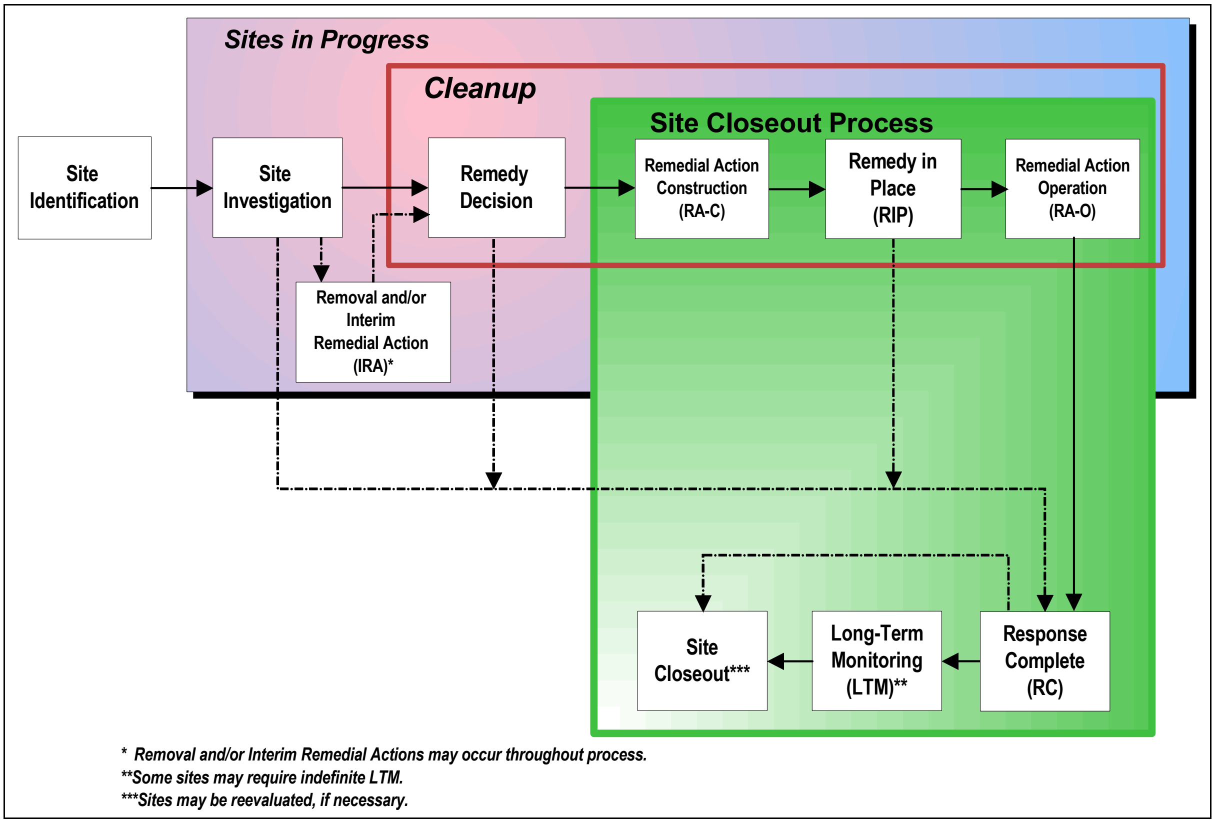

Figure 1. The major phases of environmental cleanup process. A site starts with site identification and site investigation phase and goes through some or all of the phases. Site *closeout* takes place when a site completes all the necessary phases (From [BRACO 1999]).

B. SITE CHARACTERISTICS

BRACO funds environmental cleanup of sites on installations that are closing or being realigned and has detailed cost estimation data for every site [Martin 2001]. Table 1 shows the funding request for a specific site. BRACO's yearly budget from 2002 to 2007 for environmental cleanup at these installations, totaling over $414 million, is not enough to support every installation's complete funding request.

FUNDING REQUEST OF A SPECIFIC SITE														
Phase Name	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
SI														
RI	900													
RD		200												
RAC		1200												
RAO														
LTM				90	90	90	90	90	90	90	90	90	90	450
IRA														

Table 1. Yearly funding request (in thousands of dollars) for each environmental cleanup phase of a site at Camp Bonneville. This site has no request for the SI and IRA phases. The empty cells represent no cost (no funding request).

Besides the cost estimation data (funding request), BRACO also knows some other important characteristics about every site. These site characteristics include the presence of unexploded ordnance, existing legal agreements that mandate the site be funded as requested (called *must-fund*), planned reuse date (the estimated date that the site will be given to a civilian authority), and relative risk (determined as low, medium, or high based on an evaluation of contaminants, pathways and human and ecological receptors in ground water, surface water, sediment, and surface soils [DoD 1997]).

C. THESIS OUTLINE

Chapter II introduces the deterministic BAEC model from Oremis [2000], which serves as the basis to develop the stochastic model for our analysis. Chapter III describes some operations research literature related to the work done in this thesis. Chapter IV describes the stochastic model as well as the approximating problem used to obtain a solution. Chapter V presents results. Finally, Chapter VI gives the conclusions and recommendations.

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II. DETERMINISTIC BAEC MODELS

Oremis [2000] introduces an integer-linear program called BAEC (Budget Allocation for Environmental Cleanup). BAEC data for each site contain a yearly funding request in addition to some other site characteristics (e.g., site reuse date, relative risk, existing legal agreements and presence of unexploded ordnance) that help determine the relative benefit of adhering to the funding request.

Oremis [2000] assumes that projects at sites can either be (1) delayed zero, one, two, three, four, or five years (respectively called options *opt1* through *opt6*), (2) delayed for a minimum number of years (called *must-delay*), (3) incrementally funded, or (4) funded according to the input funding timetable (*must-fund*). The BAEC model serves as the basis for the stochastic model in this thesis. The formulation from Oremis [2000] is:

A. BAEC MODEL

<u>Indices</u>

m	major army commands/Macoms (AMC, FORSCOM, MDW, MEDCOM, MTMC, TRADOC, and USARPAC);
i	installation (Alabama, Letterke, Moines, Pickett, Savanna, Sheridan, etc.);
s	site (a sub-element of an installation such as a training area);
o	site phase fund option (opt1,opt2,…,opt6);
t	year (2000, 2001, …, 2015);
p	environmental cleanup phase (SI, RI, RD, etc.).

<u>Index Sets</u>

$SITE_i$	set of sites at installation i;
$FORT_m$	set of installations belonging to MACOM m;
$OPTION_s$	set of options for site s.

Data

$PCOST_{opst}$ phase p cleanup cost in year t at site s for option o (thousands of dollars);

$COST_{ost}$ cleanup cost in year t at site s for option o (thousands of dollars) ($COST_{ost} = \sum_{p} PCOST_{opst}$);

$MINF_{it}$ minimum budget for installation i in year t (thousands of dollars);

$MAXF_{it}$ maximum budget for installation i in year t (thousands of dollars);

$MINM_{mt}$ minimum budget for MACOM m in year t (thousands of dollars);

$MAXM_{mt}$ maximum budget for MACOM m in year t (thousands of dollars);

BG_t maximum budget available for all installations in year t (thousands of dollars);

$BVALUE_{os}$ benefit value for option o at site s (utility points);

$PENBG_t$ penalty for violating the total budget in year t (utility point/ thousands of dollars);

$PENFA_{it}$ penalty for violating installation i 's maximum budget in year t (utility point/ thousands of dollars);

$PENFB_{it}$ penalty for violating installation i 's minimum budget in year t (utility point/ thousands of dollars);

$PENMA_{mt}$ penalty for violating MACOM m 's maximum budget in year t (utility point/ thousands of dollars);

$PENMB_{mt}$ penalty for violating MACOM m 's minimum budget in year t (utility point/ thousands of dollars).

Variables

y_{os} Equal to one if site s receives option o (get funding under option o) and zero otherwise;

efa_{it} allocation in excess of installation i 's maximum budget in year t (thousands of dollars);

efb_{it} allocation below installation i 's minimum budget in year t (thousands of dollars);

ema_{mt} allocation above MACOM m 's maximum budget in year t (thousands of dollars);

emb_{mt} allocation below MACOM m 's minimum budget in year t (thousands of dollars);

ebg_t amount allocated above the total year t budget (thousands of dollars).

Formulation

Maximize

$$\sum_{s}\sum_{o\in OPTION_s} BVALUE_{os}y_{os} - \sum_{it} PENFA_{it}efa_{it} - \sum_{it} PENFB_{it}efb_{it}$$
$$-\sum_{mt} PENMA_{mt}ema_{mt} - \sum_{mt} PENMB_{mt}emb_{mt} - \sum_{t} PENBG_t ebg_t$$

Subject to

$$MINF_{it} - efb_{it} \le \sum_{s\in SITE_i}\sum_{o\in OPTION_s} COST_{ost}y_{os} \le MAXF_{it} + efa_{it} \qquad \forall i,t \; (1)$$

$$MINM_{mt} - emb_{mt} \le \sum_{i\in FORT_m}\sum_{s\in SITE_i}\sum_{o\in OPTION_s} COST_{ost}y_{os} \le MAXM_{mt} + ema_{mt} \qquad \forall m,t \; (2)$$

$$\sum_{s}\sum_{o\in OPTION_s} COST_{ost}y_{os} \le BG_t + ebg_t \qquad \forall t \; (3)$$

$$\sum_{o \in OPTION_s} y_{os} = 1 \qquad \forall s \quad (4)$$

$$y_{os} \in \{0,1\} \qquad \forall s, o \in OPTION_s \quad (5)$$

$$efa_{it}, efb_{it} \geq 0 \quad \forall i,t \qquad ema_{mt}, emb_{mt} \geq 0 \quad \forall m,t \qquad ebg_t \geq 0 \quad \forall t \qquad (6)$$

The objective function seeks to maximize the overall benefit less the penalty for violating various budget targets. Constraints (1) enforce yearly installation budget limits or measure their violation, constraints (2) enforce yearly MACOM budget limits or measure their violation, and constraints (3) enforce yearly total budget limits or measure their violation. Finally, constraints (4) ensure that every site receives funding (gets a funding option).

There are four different versions of BAEC: CBAEC-1, CBAEC-2, BAEC-1, and BAEC-2. The models CBAEC-1 and BAEC-1 use six cleanup options, funding each site either as requested or by delaying cleanup one to five years. The model variations CBAEC-2 and BAEC-2 are the same as CBAEC-1 and BAEC-1 except that they have three more cleanup options (*opt7*, *opt8*, and *opt9*). In option *opt7*, all funding is delayed one year after the Site Investigation (SI) phase, and in options *opt8* and *opt9*, funding is delayed two and three years after the SI phase respectively [Oremis 2000].

The integer linear programs BAEC-1 and BAEC-2 are the same as the linear programs CBAEC-1 and CBAEC-2 except that they make sure the cleanup at each site is done by using exactly one cleanup option. Linear programs CBAEC-1 and CBAEC-2 relax the binary restriction on the y_{os} variables and thereby can suggest alternative funding options that are convex combination of the basic options. In this thesis we use the BAEC-1 version as the basis to develop a stochastic model and refer to it as simply BAEC in the remaining chapters.

III. RELATED LITERATURE

The BAEC models from Oremis [2000] successfully allocate funds to installations for environmental cleanup. However, BAEC does not directly consider how actual costs for environmental cleanup as well as the estimates can change over time.

This thesis modifies BAEC and extends it to account for uncertainty in environmental costs. To accomplish this, it primarily uses techniques associated with stochastic optimization (stochastic linear and integer programming) and persistence in optimization. Stochastic linear programs are linear programs in which some of the problem data (i.e., input data) are uncertain [Birge and Louveaux 1997]. In our situation, data uncertainty can be related to the cost of environmental cleanup with estimates of these costs updated at least annually. With the cost data used by Oremis [2000] and the updated data provided by Martin [2001], we compare the sites based on their yearly phase funding requests. This analysis shows that the yearly changes in cost estimates have been in the range (-100%, +32,900%).

There are several papers in the Operations Research literature related to stochastic optimization, budget allocation and persistence in optimization. Oremis [2000] references several deterministic budget allocation studies that are current as of this thesis. The rest of this section focuses on two publications and their applicability to the analysis done in this thesis.

In the early 1980s, the Arizona Department of Transportation started a massive program to develop a unique pavement management system [Golabi, Kulkarni, and Way 1982]. In 1982 the Arizona Department of Transportation Pavement Management System used a Markov process to describe the deterioration of pavement conditions due to traffic and weather and the improvement that can be achieved at various funding levels. They used a linear programming to minimize the total cost to the agency for maintaining the highway network at the desired or specified standard. Wang and Zaniewski [1996] enhanced that by directly incorporating data built up over 10 years on how highway conditions can probabilistically change over time. They use stochastic

linear optimization to allocate funds for highway maintenance based on predictions of how a highway's future condition changes at different funding. Their allocation of funds for the highways using stochastic optimization is similar to how we could allocate funds to the installations in this thesis if we had a model of how cost will change over time based on fund and no fund options.

The paper by Brown, Dell, and Wood [1997] states the importance of *persistence* in optimization and shows how it can be modeled. They introduce a different perspective to deal with changing input data. In their paper, the authors state that some optimization models may not be practical for implementation because they may amplify small input changes into drastically different solutions. They describe how these models are used in the real world: We use a model to produce a plan, and the plan is published. When revised data become available, we incorporate these into our original model and solve the revised model with some or all of original decision variables. Eventually, we publish a revised plan. This cycle continues periodically. This causes managers to face revisions in their plans and managers resist drastic changes in plans, which may arise in the optimization, unless they have a compelling reason to do so. Therefore, the authors claim that new plans that maintain the features of prior published plans are more acceptable to decision makers than the ones that require unwarranted drastic changes. So, there is a need to develop methods for incorporating this kind of *persistence* in modeling linear, mixed-integer, and integer linear programs. In this thesis, we develop a new stochastic model, BAECS, that trades off the benefit of resembling a prior published plan and the penalty associated with exceeding the available yearly budget.

IV. STOCHASTIC BAEC MODEL

This thesis compares the past cleanup cost data (used by Oremis [2000]) with the new data (provided by Martin [2001]) as a basis to build a predictive model for the possible changes to future costs. Then, we use a simple recourse optimization model from stochastic programming, where the cost estimates can vary according to the predictive model outcomes.

Our primary goal is to find the best funding option for each site (binary variable y_{os}). Because the optimal option might change under different cost estimates, there exists a need to ensure that we do not deviate too much from our prior published plan unless there is a compelling reason to do so. We use persistence [Brown, Dell, and Wood 1997]: Converting some variables (y_{os}) into elastic persistent variables that incur linear penalties for deviating from their preferred values.

We make two changes to the deterministic BAEC model (Oremis [2000]) before developing the stochastic model (referred to as BAECS in the remaining chapters). The first one is the addition of a new variable called “lend” which allows the transfer of funds available in 2003 to years 2004, 2005, or 2006 (the sum of funds added to years 2004, 2005, and 2006 must equal funds subtracted from 2003). The second change is the elimination of constraints (1) and (2); the installation and MACOM budget constraints. These constraints are non-binding for the deterministic BAEC results presented in Oremis [2000] and in this thesis.

The stochastic model contains a penalty function for deviation from the old y_{os} values as well as the penalty function for going over budget in a given year. The data with the superscript symbol ~ denotes the stochastic parameters of the model.

A. SIMPLE RECOURSE MODEL

Our BAECS model is as follows (we only show the additions to the original BAEC model):

Deterministic Data

$PENOPT_{os}$	Penalty for assigning funding option *o* to site *s* which entails a deviation from the prior plan (utility points)

Random Data

$\tilde{COST}_{ost}$	Non-deterministic cost for option *o* for each site and year, with known probability distribution (thousands of dollars)

Formulation

$$\underset{y}{Max} \quad \sum_{s} \sum_{o \in OPTION_s} (BVALUE_{os} - PENOPT_{os}) y_{os} - E\{h(y; \tilde{COST})\}$$

Subject to

$$\sum_{o \in OPTION_s} y_{os} = 1 \qquad \forall s \quad (1)$$

$$y_{os} \in \{0,1\} \qquad \forall\, s, o \in OPTION_s \quad (2)$$

where

$$h(\hat{y}; \tilde{COST}) = \underset{ebg}{Min} \sum_{t} PENBG_t ebg_t$$

$$\text{subject to} \quad ebg_t \geq \sum_{s} \sum_{o \in OPTION_s} \tilde{COST}_{ost}\, \hat{y}_{os} - BG_t \qquad \forall t \quad (3)$$

$$ebg_t \geq 0 \qquad \forall t \quad (4)$$

The function $h(y, \tilde{COST})$ represents the penalties associated with deviation over the total budget in a given year. The value of this function changes as the random cost, $\tilde{COST}_{ost}$, and the new funding plan, y, change.

$PENOPT_{os}$ takes on a different value based on how a new funding option of a site compares to a prior published result. Its value directly depends on the original funding options (suggested by BAEC). If a site gets the same option from BAEC and BAECS, it

receives no penalty (i.e., $PENOPT_{os}$ is zero for that site). We assume that delaying a site's funding by one year brings a penalty of 100 utility points. This penalty is 400 points for 2 years, 1600 points for 3 years, and so on. For example, if BAEC (the prior published plan) recommends that a site get funded under *opt2* and it receives *opt3* from BAECS, the penalty is 100 points. On the other hand, this site might get option *opt1* from BAECS, which we penalize by 50 points (half).

B. APPROXIMATING PROBLEM

We develop an approximating problem to BAECS by approximating the probability distribution of $\tilde{COST}_{ost}$ using a finite number of (equally likely) outcomes. Each of these outcomes, $COST_{ostn}$, is called scenario, and is indexed by $n \in N$, where N is the scenario set. We also require the over-budget allocation variable to depend on the scenario, becoming ebg_{tn}.

Our approximating BAECS model is as follows (we only show the additions to the original BAEC model):

Indices

$n \in N$ scenario index.

Data

$COST_{ostn}$ cleanup cost in year *t* at site *s* for option *o* under scenario *n* (thousands of dollars).

Variable

ebg_{tn} amount allocated above the total year *t* budget under scenario *n* (thousands of dollars).

Formulation

$$\text{Max} \quad \sum_{s} \sum_{o \in OPTION_s} (BVALUE_{os} - PENOPT_{os}) y_{os} - \frac{1}{|N|} \sum_{t} \sum_{n} PENBG_t ebg_{tn}$$

Subject to

$$ebg_{tn} \geq \sum_{s} \sum_{o \in OPTION_s} COST_{ostn}\, y_{os} - BG_t \qquad \forall t,n \quad (1)$$

$$\sum_{o \in OPTION_s} y_{os} = 1 \qquad \forall s \; (2)$$

$$y_{os} \in \{0,1\} \qquad \forall\, s, o \in OPTION_s \quad (3)$$

$$ebg_{tn} \geq 0 \qquad \forall t,n \; (4)$$

V. IMPLEMENTATION AND RESULTS

BRACO provided all the necessary BAEC input data for 334 sites from 54 different installations.

A. DATA

We have the following information about each site:

1) the yearly phase funding request (cost estimate) for each site from 2002 to 2015;
2) the yearly BRACO budget available for all installations from 2002 to 2007 (we assume that yearly budgets from year 2008 to 2015 are unlimited); and
3) initiation and completion time for all phases of cleanup at every site.

Table 2 provides the comparison between the yearly BRACO budgets and the total funding requests from installations for those years.

TOTAL FUNDING REQUEST (COST) AND AVAILABLE BUDGET FOR ALL SITES						
Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**
Cost	161,130	148,748	78,230	62,707	56,445	49,914
Available	127,670	132,456	48,319	39,375	30,871	35,555
Available/Cost (%)	79.23%	89.05%	61.77%	62.79%	54.69%	71.23%

Table 2. The yearly total funding requests (cost estimate) for all sites (in thousands of dollars), the available budget for BRACO and the percentage of available money. For instance, the total funding request for 2002 is $161,130,000 but BRACO has only $127,670,000 (only 79.23%) available for that year.

B. DETERMINISTIC MODEL (BAEC) RESULTS

In order to analyze the solution from BAECS (stochastic model), we first need to solve BAEC (deterministic model). We use a personal Hewlett Packard laptop computer with 128 Megabyte of random access memory and a 800 Megahertz Intel Pentium processor. We generate BAEC and BAECS using the GAMS (General Algebraic Modeling System) Version 2.50D [GAMS 1998] and solve them using the XA solver [Sunset Software Technology 2001].

BAEC consists of approximately 350 constraints and 1,100 variables, of which approximately 800 are binary variables. BAECS with 50 scenarios consists of about

1,200 constraints and 3,800 variables, of which approximately 800 are binary variables. It takes less than half a minute to generate and solve BAEC to optimality, and no more than 11 minutes to generate and solve BAECS to optimality.

There are 334 sites but 192 (57.5%) are must-funds for all results reported in this thesis (they have to be funded as requested, option *opt1*). Only the following installations contain sites that can be delayed: Alabama AAP, ARL-Watertown, Camp Bonneville, Fort Chaffee, Camp Kilmer, Fort Mcclellan, Pueblo Chemical Depot, Red River Army Depot, Savanna Depot Activity, Fort Sheridan, Sierra Army Depot, Stratford Army Engine Plant.

As Table 3 shows, BAEC suggests annual funding allocations between years 2002 and 2007. For these results, BAEC transfers $12,291,000 from year 2003 to years 2004 ($6,198,000), 2005 ($5,911,000), and 2006 ($182,000). The objective function value, which represents the total benefit less the penalty associated with deviation over the yearly total budget, is 13,457.85 (utility points). All installations except for 5 of them receive full funding (100%) every year. The installations (totally 5 out of 54) with incomplete funding are Camp Bonneville, Fort Mcclellan, Pueblo Chemical Depot, Red River Army Depot, and Savanna Depot Activity. Incomplete funding causes some delays in the completion time of some sites at these installations.

Year	AMC	FORSCOM	MDW	MEDCOM	MTMC	TRADOC	USARPAC	Plan	BAEC	Available
2002	56,805	19,585	5,018	80	8,978	36,756	420	161,130	127,642	127,670
2003	76,610	10,371	1,546	80	273	30,875	300	148,748	120,055	132,456
2004	20,307	1,662	512	80	168	31,637	151	78,230	54,517	48,319
2005	20,173	1,823	628	80	128	22,305	149	62,707	45,286	39,375
2006	12,631	1,766	507	40	113	15,946	50	56,445	31,053	30,871
2007	11,199	3,907	549	40	141	19,164	0	49,914	35,000	35,555
Y-total	197,725	39,114	8,760	400	9,801	156,683	1,070	557,174	413,553	414,246

Table 3. The funding requests (in thousands of dollars) at the MACOM level for years between 2002 and 2007 and the amount of money allocated by BAEC for those years. For instance, in 2005 AMC requests $20,173,000 and all MACOMs request $62,707,000 totally (under "plan" column). However, for that year BAEC only allocates $45,286,000 (under "BAEC" column), a difference of $17,421,000. The "Available" column represents the available yearly budgets.

Table 4 shows the percentage of funding allocated to installations by BAEC that are under 100%.

YEARLY PERCENT BUDGET ALLOCATION FOR EACH INSTALLATION														
installation	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**
ALABAMA														
ARLWATER														
ARLWOOD														
BAYONNE														
BELLMORE														
BONNEVILL	**44.13**	**25.9**	**0.27**	**2.52**	**2.52**	**30.65**				**96.55**	**59.74**	**2,845**	**2,845**	**2,238**
CAMERON														
CEKELLY														
CHAFFEE														
DETROIT														
DEVENS														
DIXBRAC														
EASTBAKE														
FITZSIMON														
GREELY														
HAMILTON														
HARRISON														
HERNDON														
HINGHAM														
HOLABIRD														
HUNTER														
JEFFERSON														
KILMER														
LETTERKE														
LEXINGTON														
LIVINGSTON														
LOMPOC														
MCCLELLAN	**60.06**	**44.5**	**54.77**	**40.4**	**18.3**	**53.44**	**175**	**1,194**	**1,786**	**2,093**	**1,839**	**1,078**	**136.9**	
MEADE														
MOINES														
MONMOUTH														
NIKEKANSAS														
OAKLAND														
PEDRICKTO														
PICKETT														
POMORD														
PRESIDIO														
PUEBLO	**68.28**	**145**	**101.8**	**105**	**97.7**	**96.91**	**71.3**	**39.7**	**63.99**	**93.78**	**207.6**	**303.9**	**283.4**	**113.3**
REDRIVER		**9.59**	**49.07**	**41**	**58.3**	**53.23**	**8,834**	**189.9**	**131.1**					**114.2**
RIOVISTA														
RITCHIE														
SACRAMEN														
SAVANNA	**14.39**	**135**	**32.56**	**121**	**34.5**	**55.95**	**69.1**	**72.09**	**158.5**	**182.2**	**160.3**	**189**	**162.2**	**144.5**
SENECA														
SHERIDAN														
SIERRA														
STRATFORD														
SUDBURY														
TACONY														
TOOELE														
TOTTEN														
UMATILLA														
VINTHILL														
WINGATE														

Table 4. The percentage of funding allocated to each installation by BAEC. Only 5 out of 54 installations do not get full funding every year. Empty cells represent full funding.

As Table 5 indicates, the total number of sites requested for closeout between years 2002 and 2007 is currently 210. However, BAEC, with its limited annual budget, recommends closing only 201 sites (a difference of nine).

TOTAL SITE CLOSEOUT			
Years	**Plan**	**BAEC**	**Difference**
2002	93	87	-6
2003	63	58	-5
2004	35	35	0
2005	13	12	-1
2006	3	6	3
2007	3	3	0
Total	210	201	-9

Table 5. The number of sites requested for closeout and the solution by BAEC. The "Plan" column represents the total number of sites requested for closeout for every year whereas the "BAEC" column shows the number of sites BAEC recommends for closeout.

C. GENERATION OF NEW COST ESTIMATES FOR BAECS

We have two sets of data for cost analysis. The first one shows the changes in cumulative cost estimates from FY1995 through FY2000 (the changes in total costs spent and expected to be spent, for every year for all installations) [Tarantino 2001], and the second contains the old and new detailed cost data for every site (as of 2000 and 2001) [Martin 2001]. We use the second one for our analysis because we think changes in past years' cumulative cost estimates are not a good predictor for future yearly cost estimates of a site (it is harder to predict a site's future yearly cost estimate by using the changes in cumulative cost estimates). We compare the old and new cost estimates of each site and each phase of environmental cleanup. From this comparison data, we determine the total change in every installation's yearly funding request.

Table 6 provides the comparison data for a specific site at a specific installation. The old data (e.g., old 2002) is the cost estimate (in thousands of dollars) used by Oremis [2000]. The new estimate (e.g., new 2002) is the one that this thesis uses. For instance, one year ago the funding request for the RAO phase of environmental cleanup at a site of this installation was $437,000 for year 2002, but the request changed a year later: now the installation requests $472,000 instead (approximately an 8% increase). This installation's

total funding request for year 2002 has increased from $753,000 to $866,000 (a 15% increase).

COMPARISON OF OLD AND NEW COST DATA									
Site	**Phase**	**Old 2002**	**New 2002**	**Old 2003**	**New 2003**	**Old 2004**	**New 2004**	**Old 2005**	**New 2005**
Site1	SI								
Site1	RI								
Site1	RD								
Site1	RAC								
Site1	RAO	437	472	465	502	425	459	375	405
Site1	LTM								
Site1	IRA								
Site2	SI								
Site2	RI								
Site2	RD								
Site2	RAC								
Site2	RAO	316	394	316	360	287	360	287	360
Site2	LTM								
Site2	IRA								
	Total	753	866	781	862	712	819	662	765

Table 6. The old (as of 2000) and new (as of 2001) funding requests (in thousands of dollars) for two sites of a specific installation. For instance, this installation originally requested $465,000 for the RAO phase of site1 for year 2003 but its request is now $502,000. Overall the installation's funding request has increased for the years shown. Empty cells represent zeros.

Based on data represented by Table 6, we determine the percent changes in each installation's funding request (Table 7). For example, Fort Chaffee's total estimates for 2002 decrease by 3.39%. Some installations have drastic changes in certain years. For instance, ARL-Watertown had requested $11,000 for year 2002 but now it requests $898,000 (more than a 8,000 % increase).

PERCENTAGE CHANGES IN COST ESTIMATES OF INSTALLATIONS			
Installation	2002	2003	2004
ALABAMA	-86 (-39.81%)	372 (172.22%)	0 (0.00%)
ARLWATER	887 (8,063.64%)	106 (757.14%)	996 (7,661.54%)
ARLWOOD	-17 (-6.44%)	44 (32.84%)	1 (0.76%)
BAYONNE	-6,458 (-100.00%)	-3,827 (-100.00%)	-2,241 (-100.00%)
BONNEVILLE	2,997 (330.07%)	2,402 (39.57%)	4,994 (236.01%)
CAMERON	-234 (-48.75%)	46 (657.14%)	46 (657.14%)
CEKELLY	-1 (-3.03%)	32 (32,900.00%)	0 (0.00%)
CHAFFEE	-17 (-3.39%)	-85 (-21.14%)	-78 (-21.49%)
DETROIT	0 (0.00%)	0 (0.00%)	0 (0.00%)

Table 7. The total change between cost estimates available in 2000 and 2001 of nine installations. The first number for every year shows the change in thousands of dollars whereas the number in parenthesis shows the percent change. For instance, Alabama AAP's estimate for 2002 has decreased by $86,000 (a 39.81% decrease).

In order to generate new cost estimates for BAECS, we randomly generate estimates based on the percent changes shown above. We assume that cost estimates have a normal distribution and we take the original cost estimates multiplied by the percent changes above as the mean values for the normal distribution and 10% of these values as the standard deviation. We pick a normal distribution and a 10% standard deviation for demonstration purposes only. When additional data are available, we recommend further research to determine the most appropriate distribution.

We also assume that all sites at the same installation experience the same change in a given year with estimates changing from year to year. Finally, we assume that if the old cost estimate is zero dollars, the new one is also zero dollars. Table 8 provides an example.

GENERATION OF NORMAL COST ESTIMATES					
Phases	**2002 change**	**Original cost**	**Scenario 1**	**Scenario 2**	**Average of 2 scenarios**
SI	6.50% increase				
RI	6.50% increase	69.00	70.42	68.97	69.70
RD	6.50% increase				
RAC	6.50% increase				
RAO	6.50% increase				
LTM	6.50% increase				
IRA	6.50% increase				

Table 8. Generation of normal future cost estimates (in thousands of dollars) for a site at Jefferson Proving Ground. This site currently requests $69,000 for the RI phase in 2002. The "Scenario 1" and "Scenario 2" columns show the new estimates (funding requests) for this site for year 2002 based on the percent change and normal distribution. Empty cells represent zero dollars (no request or cost).

D. STOCHASTIC MODEL (BAECS) RESULTS

We solve our BAECS approximating problems four times with 2, 10, 30, and 50 scenarios. There appears to be little value in exceeding 50 scenarios because it takes longer to solve and solutions do not change significantly. We use BAECS itself to refer to the BAECS approximating problem with 50 scenarios in the remaining chapters unless specified otherwise.

The BAECS approximating problem with 2 scenarios has an objective function value of $-141{,}564{,}000$ (utility points). The objective function value for the deterministic model (BAEC) is 13,457.85. This big decrease is due to high penalties for going over budget and also for deviation from the original values of funding options for sites. For instance, in 2002 our budget is $127,670,000 but over budget deviations in each of the two scenarios are $218,886,000 and $222,477,000 respectfully. This is a large deviation. Therefore, it brings a high penalty.

If we consider our objective function in three parts, it is easier to understand the change in values: The objective function is the sum of benefits for all sites less the expected penalty for going over budget and the penalty for deviating from original funding option values. Below is the equation for the objective function and an example.

Objective function (total benefit)

= Sum of benefits – expected penalty for budget deviation

– penalty for deviation from original funding options

Objective function (BAECS approximating problem with 2 scenarios)

= 10,362 - 141,192,500 - 381,500

= -141,563,638.

Table 9 shows how these values change little as we increase the number of scenarios in our approximating problem for BAECS.

OBJECTIVE FUNCTION VALUES FOR APPROXIMATING PROBLEMS				
Approximating Problems	**Benefit**	**Penalty1**	**Penalty2**	**Objective function value**
2 Scenarios	10,362	141,192,500	381,500	-141,563,638
10 Scenarios	10,344	141,075,000	380,400	-141,445,056
30 Scenarios	10,324	141,264,500	381,700	-141,635,876
50 Scenarios	10,342	141,147,700	382,800	-141,520,158

Table 9. The comparison of approximating problems (for BAECS) in terms of objective function values. Penalty1 represents the penalty for going over budget and penalty2 represents the penalty for deviating from original y_{os} (funding option) values. All numbers are in utility points and vary little as we change the number of scenarios.

Because we have 192 must-fund sites, BAECS has the flexibility to possibly change the funding options of only 142 sites (42.5% of 334 total sites). As a result of solving BAECS, we see that 114 sites (out of 142 possible) get different funding options (their original funding options change). This means almost 80% of the sites with a possibility to change their funding options experience a change (Table 10). This is probably not surprising because most installations' percent changes in total cost estimates (Table 7) are very drastic.

We look at all installations together and compare the funding option distribution suggested by both BAEC and BAECS. Table 10 provides this comparison by showing the changes in funding options for all installations. For instance, Fort Mcclellan contains 22 sites, of which four of them are must-fund sites. Fifteen of the remaining 18 sites get a different funding option from BAECS. So 83.33% of the sites with a possibility of change experience a change under BAECS.

INSTALLATION FUNDING OPTION CHANGES					
Installation	**Total Sites**	**Must-fund Sites**	**Sites with possibility of change**	**Sites experiencing change**	**Percentage**
ALABAMA	4	3	1	1	100.00%
ARLWATER	2	0	2	2	100.00%
ARLWOOD	**10**	**10**	**0**	**0**	**none**
BAYONNE	**4**	**4**	**0**	**0**	**none**
BONNEVILLE	6	3	3	1	33.33%
CAMERON	**2**	**2**	**0**	**0**	**none**
CEKELLY	**1**	**1**	**0**	**0**	**none**
CHAFFEE	3	1	2	2	100.00%
DETROIT	**1**	**1**	**0**	**0**	**none**
DEVENS	**18**	**18**	**0**	**0**	**none**
FITZSIMONS	**4**	**4**	**0**	**0**	**none**
GREELY	**7**	**7**	**0**	**0**	**none**
HAMILTON	**3**	**3**	**0**	**0**	**none**
HERNDON	**1**	**1**	**0**	**0**	**none**
JEFFERSON	**25**	**25**	**0**	**0**	**none**
KILMER	1	0	1	1	100.00%
LETTERKE	**6**	**6**	**0**	**0**	**none**
LEXINGTON	**13**	**13**	**0**	**0**	**none**
LIVINGSTON	**1**	**1**	**0**	**0**	**none**
MCCLELLAN	22	4	18	15	83.33%
MEADE	**6**	**6**	**0**	**0**	**none**
MOINES	**2**	**2**	**0**	**0**	**none**
MONMOUTH	**1**	**1**	**0**	**0**	**none**
OAKLAND	**11**	**11**	**0**	**0**	**none**
PICKETT	**5**	**5**	**0**	**0**	**none**
POMORD	**10**	**10**	**0**	**0**	**none**
PUEBLO	56	8	48	35	72.92%
REDRIVER	10	2	8	6	75.00%
RITCHIE	**2**	**2**	**0**	**0**	**none**
SACRAMENTO	**2**	**2**	**0**	**0**	**none**
SAVANNA	53	1	52	45	86.54%
SENECA	**18**	**18**	**0**	**0**	**none**
SHERIDAN	6	1	5	4	80.00%
SIERRA	1	0	1	1	100.00%
STRATFORD	1	0	1	1	100.00%
SUDBURY	**1**	**1**	**0**	**0**	**none**
TACONY	**1**	**1**	**0**	**0**	**none**
TOOELE	**3**	**3**	**0**	**0**	**none**
UMATILLA	**3**	**3**	**0**	**0**	**none**
VINTHILL	**1**	**1**	**0**	**0**	**none**
WINGATE	**7**	**7**	**0**	**0**	**none**
Total	334	192	142	114	80.28%

Table 10. The changes in funding options of all sites. Installations highlighted in bold contain all must-fund sites (no delay in receiving funding). Out of 142 sites with a possibility of change, 114 of them experience it (approximately 80.28%).

Out of the 114 sites with changes, 84 sites previously obtained option *opt1* from BAEC. Table 11 shows the delay that these 84 sites experience as a result of BAECS.

CHANGES IN FUNDING OPTIONS FOR SITES WITH OPT1 FUNDING							
	Originally opt1 from BAEC	Sites changing from opt1	Now opt2	Now opt3	Now opt4	Now opt5	Now Opt6
Number of sites	87	84	20	24	26	6	8
Percentage	100%	96.55%	22.99%	27.59%	29.89%	6.90%	9.20%

Table 11. The changes in funding options of the sites that originally receive option *opt1* (from BAEC) as a result of BAECS. BAEC funds 87 of the 142 non must-fund sites with *opt1*. BAECS changes the funding options of 84 of these 87 sites. For instance, as a result of BAECS, 20 of the 84 sites switch to option *opt2*.

Table 11 shows that most of the sites (84 out of 87) that previously obtain option *opt1* (no delay in funding) from BAEC now get options *opt2*, *opt3*, or *opt4* (one, two or three year delay in receiving funding) from BAECS. The majority of sites do not experience a large delay.

E. IMPLEMENTATION OF RESULTS FROM BAECS IN BAEC

We compare the results (i.e., objective function value, budget deviations, lending money, yearly allocations) using the funding options recommended by BAEC in section B of this Chapter and results by using the funding options suggested by BAECS. Table 12 summarizes results.

COMPARISON OF DETERMINISTIC AND STOCHASTIC MODEL FUNDING OPTIONS							
	Total Number of sites	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6
BAEC	334	279	15	26	3	1	10
BAECS	334	195	20	39	32	14	34

Table 12. The funding options suggested by BAEC and BAECS. BAEC funds 279 sites out of 334 total without any delay whereas BAECS funds only 195 out of 334 sites as requested.

Table 13 shows the differences in some of the results between BAEC and BAECS. As seen on this table, the biggest difference between the two solutions (based on the funding options provided by both models) is the over budget deviation. With BAEC we do not exceed the available budget in any year. However, the funding option solution recommended by BAECS causes us to exceed it in 2007 by $21,338,000. In the new solution we do not transfer as much money from year 2003 to years 2004, 2005, and 2006. Finally, because BAECS has less sites with option *opt1*, it does not use as much

money in early years (2002-2004) compared to BAEC (i.e., with BAEC, deviation below budget in 2002 is $28,000 whereas it is $6,584,000 with BAECS).

Year	Budget	Dev below old	Dev below new	Dev above old	Dev above new	Lending old	Lending new
2002	127,670	28	6,584				
2003	132,456	110	35,231			(12,291)	(5,490)
2004	48,319		590			6,198	
2005	39,375					5,911	1,423
2006	30,871					182	4,067
2007	35,555	555			21,338		

Table 13. The comparison of results from BAEC with the original and new funding options (coming from BAECS). With the original set of options we do not go over budget at all. However, with the new set of funding options coming from BAECS, we go over budget in 2007 by $21,338,000. "Dev below old" and "Dev above old" represent deviations below budget and above budget based on the original funding option solutions. The "Lending old" column represents the amount of money transferred from year 2003 to years 2004, 2005, and 2006 under BAEC. All numbers are in thousands of dollars. Empty cells represent zeros.

The number of installations with incomplete funding in certain years increases under BAECS. With BAEC solution we have only 5 installations but with BAECS solution we have 12. The installations from the original list (Table 4) still appear in the new solution: Camp Bonneville, Fort Mcclellan, Pueblo Chemical Depot, Red River Army Depot, and Savanna Depot Activity. The extra ones are Alabama AAP, Fort Chaffee, Camp Kilmer, ARL-Watertown, Fort Sheridan, Sierra Army Depot and Stratford Army Engine Plant. When we compare the number of sites that both models suggest for closeout in each year, we notice a considerable change (Table 14). Between years 2002 and 2007 BAEC recommends 201 sites out of 210 total (a difference of nine) for closeout whereas BAECS suggests only 192 (a difference of eighteen).

TOTAL SITE CLOSEOUT BASED ON OLD AND NEW FUNDING OPTIONS					
Years	Plan	BAEC	BAECS	BAEC difference	BAECS difference
2002	93	87	59	-6	-34
2003	63	58	33	-5	-30
2004	35	35	29	0	-6
2005	13	12	33	-1	20
2006	3	6	17	3	14
2007	3	3	21	0	18
Total	210	201	192	-9	-18

Table 14. The comparison of solutions from BAEC and BAECS in terms of the number of sites for closeout. BAEC recommends closing 58 sites out of 63 in 2003 whereas BAECS suggests only 33.

BAECS recommends not spending all the money in the first few years. It suggests shifting the funding forward as a result of anticipating an overall increase in future costs. This hedging strategy seems to offer a more conservative and cautious approach for funding sites compared to BAEC, which considers the current cost estimates as nonchanging.

F. CHANGING THE PENALTY LEVEL

Both BAEC and BAECS try not to exceed the available budget due to the high penalty incurred. In this section, we vary the penalty level for going over budget from its current level of 100 (utility points) discounted 5% per year. Table 15 shows the changes in objective function values in BAECS as a result of varying penalty level.

	Deter.	Pen=100	Pen=50	Pen=10	Pen=1	Pen=0.0001
Benefit(utility)	13,457	10,342	10,731	11,734	13,058	13,457
Penalty1(utility)	0	141,147,700	70,645,133	14,186,532	1,447,154	160
Penalty2(utility)	0	382,800	284,900	138,300	33,700	0
Obj. function(utility)	13,457	-141,520,158	-70,919,302	-14,313,098	-1,467,796	13,297
AFTER IMPLEMENTATION						
Obj.function(utility)	13,457	-1,479,769	-1,103,325	-473,888	-702,876	13,457
Over budget 2007	0	21,338	15,953	6,954	10,252	0
Lend 2003	(12,291)	(5,490)	(13,098)	(20,216)	(10,601)	(12,291)
Lend 2004	6,198	0	682	2,850	10,601	6,198
Lend 2005	5,911	1,423	2,418	11,454	0	5,911
Lend 2006	182	4,067	9,998	5,912	0	182
Under budget 2002	28	6,584	6,284	4,850	1,516	28
Under budget 2003	110	35,231	27,054	16,332	12,257	110
Under budget 2004	0	590	0	0	0	0
Under budget 2005	0	0	0	0	832	0
Under budget 2006	0	0	0	0	433	0
Under budget 2007	555	0	0	0	0	555

Table 15. The comparison of BAEC and BAECS based on varying penalty level. Penalty1 represents the penalty for going over budget and penalty2 is the penalty for deviating from the original funding option values. The "Over budget 2007" row shows the amount over budget in 2007 (in thousands of dollars). Lend values show how much money we transfer from year 2003 to years 2004, 2005, and 2006. The "Deter." column shows the results for BAEC. The "Pen=100" column shows results for BAECS with a penalty level of 100 and so on. Finally, under budget rows show how much we do not use in that year (go under budget) in thousands of dollars.

From table 15 we see several trends as the penalty level decreases. The upper part of the table provides comparison among BAECS with different penalty levels directly. As the penalty level decreases from 100 to 0.0001, we get closer to our original BAEC funding option values (i.e., penalty2 in Table 15 drops to zero). Actually, when the penalty level is equal to 0.0001, BAEC and BAECS do not differ: they have the same optimal funding options.

When we compare the solutions that we obtain by using the funding options recommended by BAEC and BAECS with different penalty level assuming no change to the cost data, we see a common pattern: all solutions from BAECS indicate an over budget deviation in year 2007. As stated before, the BAEC solution has no such deviation. Figure 2 provides the comparison between these models based on their solutions for yearly allocations (i.e., how much money each model allocates to installations each year).

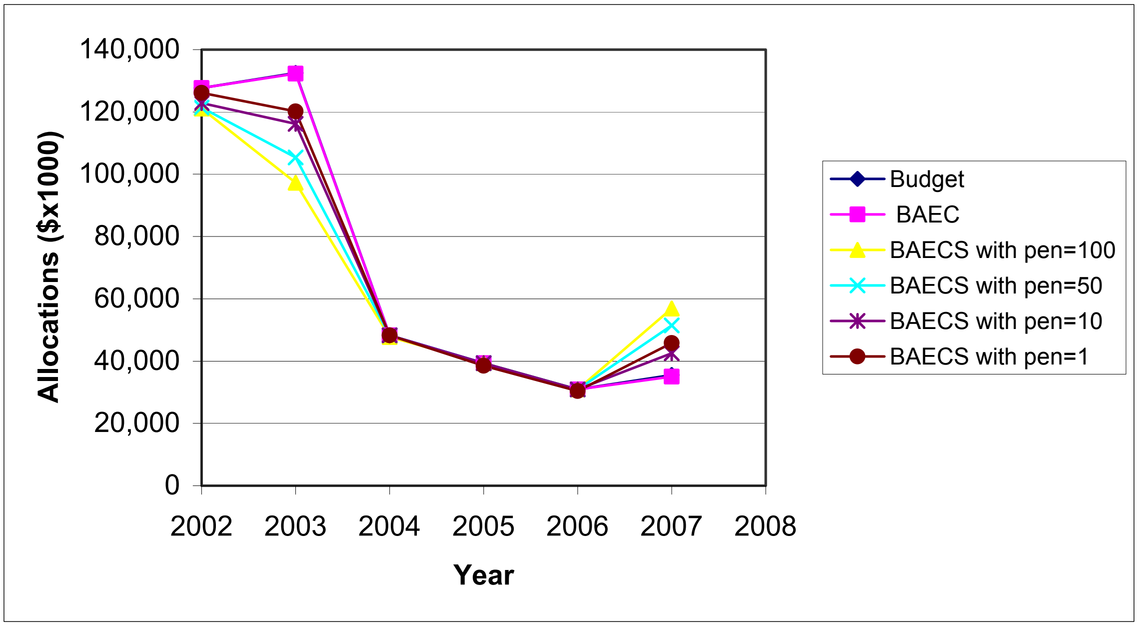

Figure 2. Yearly (BRACO) budgets versus allocations using funding options recommended by BAEC and BAECS (with different penalty level). Assuming no change to the cost data, between 2002 and 2004 all models go under budget whereas in 2007 all BAECS go over budget. All budget and model allocations are in thousands of dollars. Yearly budgets cannot be seen on the graph because BAEC allocations and yearly budget values are almost the same.

Figure 2 shows that in early years (2002 and 2003) all models besides BAEC stay away from the budget limits (they do not use all the available money). The allocation by BAECS with the lowest penalty level (pen=1) is almost the same as the one by BAEC and the yearly budget in these early years since the distribution of funding options is almost the same (Table 16). Between years 2004 and 2006 all models allocate approximately the same amount of money and are very close to the budget limits. However, in 2007 only BAEC is within budget.

Table 16 helps us understand the graph (Figure 2) better. It shows the funding option distribution recommended by BAEC and BAECS with different penalty levels.

DISTRIBUTION OF FUNDING OPTION VALUES							
Model	**opt 1**	**opt2**	**opt 3**	**opt 4**	**opt 5**	**opt 6**	**Total**
BAEC	279	15	26	3	1	10	334
BAECS with penalty=100	195	20	39	32	14	34	334
BAECS with penalty=50	208	19	34	30	19	24	334
BAECS with penalty=10	239	9	35	29	7	15	334
BAECS with penalty=1	269	11	31	8	3	12	334
BAECS with penalty=0.0001	279	15	26	3	1	10	334

Table 16. The solution for the funding option values from BAEC and BAECS with different penalty levels. Both BAEC and BAECS with a penalty level of 0.0001 have the same funding option values.

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VI. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

The United States Army Base Realignment and Closure Office (BRACO) currently uses an integer-linear program called BAEC (Budget Allocation for Environmental Cleanup) [Oremis 2000] to help determine how to allocate funds from limited yearly budgets to installations for environmental cleanup. This deterministic model helps BRACO decide how to allocate funds to installations based on the input (funding requests provided by these installations). However, it does not directly consider how much actual costs for environmental cleanup as well as the estimates can change over time. Considering the lack of this important feature, this thesis modifies the deterministic BAEC model and extends it to account for uncertainty in future environmental cost estimates.

From the data in this thesis, 192 sites out of 334 total must receive funding without delay (must-fund). The deterministic model also funds 87 of the remaining 142 sites without delay. However, as a result of solving the stochastic model by varying the cost estimates based on an analysis of past data, we see that the funding options of almost 80% of the remaining 142 sites change. We also see that all changes are in one direction: the site either gets the same funding option or gets an extra delay (no sites receive funding earlier than the time specified by the original funding option from BAEC). On the other hand, our analysis shows that most changes are not extreme (i.e., if BAEC funds a site under option *opt1*, in most cases BAECS funds it under option *opt2* or *opt3* and not under option *opt5* or *opt6*, which is a larger deviation).

Overall, BAECS recommends funding fewer sites as requested (compared to the solution by BAEC). Unlike BAEC, BAECS anticipates an overall increase in installations' future costs and therefore does not suggest spending all the budget in the earlier years (2002 through 2005). It recommends reserving some of its budget as insurance for uncertainty in future costs.

There are tradeoffs in choosing the funding option selections suggested by either BAEC or BAECS. With the BAEC solution, we base funding recommendations on current site environmental cleanup estimates and use all of the budget available to plan the closeout of more sites between 2002 and 2007. The risk with the BAEC solution is not having sufficient funds available if the actual cleanup cost increases. With the BAECS solution, we close less sites but have a better chance of staying within the available budget (according to our assumptions about how cost estimates change). The risk with the BAECS solution is not fully executing funds available and thereby unnecessarily delaying cleanup.

B. RECOMMENDATIONS

We recommend a more extensive analysis of past cleanup data to provide better estimates for BAECS. We also recommend the use of realistic budget values for all years between 2008 and 2015.

APPENDIX : MACOM AND INSTALLATIONS

This appendix shows all the installations that the United States Army Base Realignment and Closure Office is currently funding. These installations are under seven Major Army Commands (MACOMs). Table A1 shows the state, MACOM, status of each installation (Closure (C) or Realignment (R)). Major Army Commands are: Army Materiel Command (AMC), Forces Command (FORSCOM), Military District of Washington (MDW), Medical Command (MEDCOM), Military Traffic Management Command (MTMC), Training and Doctrine Command (TRADOC), and US Army Pacific Command (USARPAC).

No	MACOM	INSTALLATION	ABBREVIATION	STATE	ACTION
1	AMC	Letterkenny Army Depot	Letterke	Pennsylvania	R
2	AMC	Arl-Watertown	Arlwater	Massachusetts	C
3	AMC	Arl-Woodbridge	Arlwood	Virginia	C
4	AMC	Fort Monmouth	Monmouth	New Jersey	R
5	AMC	Vint Hill Farms Station	Vinthill	Virginia	C
6	AMC	Sacramento AD	Sacramen	California	C
7	AMC	Sierra Army Depot	Sierra	California	R
8	AMC	Alabama AAP	Alabama	Alabama	C
9	AMC	Savanna Depot Activity	Savanna	Illinois	C
10	AMC	Lexington Facility-LBAD	Lexington	Kentucky	C
11	AMC	Fort Wingate	Wingate	New Mexico	C
12	AMC	Seneca AD	Seneca	New York	C
13	AMC	Tooele Army Depot	Tooele	Utah	R
14	AMC	Pueblo Chemical Depot	Pueblo	Colorado	R
15	AMC	Umatilla Chemical Depot	Umatilla	Oregon	R
16	AMC	Jefferson Proving Ground	Jefferson	Indiana	C
17	AMC	Red River Army Depot	Redriver	Texas	R
18	AMC	Stratford Army Engine Plant	Stratford	Connecticut	C
19	AMC	Detroit Arsenal & Detroit Tank Plt	Detroit	Michigan	R
20	FORSCOM	East Fort Baker	EastBake	California	C
21	FORSCOM	Fort Hunter Liggett Brac	Hunter	California	R
22	FORSCOM	Presidio of San Francisco	Presidio	California	C
23	FORSCOM	Lompoc Branch Disciplinary Barracks	Lompoc	California	C
24	FORSCOM	Hamilton Army Air Field	Hamilton	California	C
25	FORSCOM	Rio Vista Res Training Area	Riovista	California	C
26	FORSCOM	Fort Des Moines	Moines	Iowa	C
27	FORSCOM	Fort Sheridan	Sheridan	Illinois	C
28	FORSCOM	Fort Devens	Devens	Massachusetts	C
29	FORSCOM	Hingham Annex	Hingham	Massachusetts	C
30	FORSCOM	Sudbury Training Annex	Sudbury	Massachusetts	C
31	FORSCOM	Fort Dix Brac	Dixbrac	New Jersey	R
32	FORSCOM	Camp Pedricktown	Pedrickto	New Jersey	C
33	FORSCOM	Camp Kilmer	Kilmer	New Jersey	C
34	FORSCOM	Housing Area Livingston, NJ	Livingston	New Jersey	R
35	FORSCOM	C.E.Kelly Support Facility Brac	Cekelly	Pennsylvania	R
36	FORSCOM	Tacony Warehouse	Tacony	Pennsylvania	C
37	FORSCOM	Fort Pickett	Pickett	Virginia	C
38	FORSCOM	Camp Bonneville	Bonnevill	Washington	C
39	TRADOC	Presidio of Monterey (Fort Ord Ann)	Pomord	California	C
40	TRADOC	Fort Mcclellan	Mcclellan	Alabama	C
41	TRADOC	Fort Chaffee	Chaffee	Arkansas	C
42	TRADOC	Nike Kansas City 30	Nikekansas	Missouri	C
43	TRADOC	Fort Benjamin Harrison	Harrison	Indiana	C
44	MTMC	Oakland Army Base	Oakland	California	C
45	MTMC	Military Ocean Terminal,Bayonne	Bayonne	New Jersey	C
46	MDW	Fort George G. Meade	Meade	Maryland	R
47	MDW	Fort Ritchie	Ritchie	Maryland	C
48	MDW	Cameron Station	Cameron	Virginia	C
49	MDW	Defense Mapping Agency-Herndon	Herndon	Virginia	C
50	MDW	Fort Holabird	Holabird	Maryland	R
51	MDW	Fort Totten	Totten	New York	C
52	MDW	Bellmore Logistics Activity	Bellmore	New York	C
53	MEDCOM	U.S. Army Operations Fitzsimons	Fitzsimon	Colorado	C
54	USARPAC	Fort Greely	Greely	Alaska	R

Table A1

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